

## **Visual Analysis of Requirements Flowdown**

Kenneth M. Haught  
*TASC, Inc.*

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### **Abstract**

This presentation describes techniques that have been developed by the IV&V Program for visual analysis of requirements flowdown from top-level capabilities to lower-level software components. Beginning in 2007, IV&V analyses typically performed in Excel spreadsheets or Access databases were expanded to leverage the network diagramming features within Microsoft Project. This approach allowed an IV&V analyst to “see” beyond adjacent interfaces and to visually explore system-integration issues by examining traceability across multiple boundaries. The IV&V Program has used these techniques to identify development issues on NASA projects such as Constellation and Ares, as well as supporting its internal risk-based assessments (RBAs) needed for prioritizing future IV&V activities on projects such as the Global Precipitation Measurement (GPM) effort.

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## Visual Analysis of Requirements Flowdown Overview



- **Expanded tools for analyzing trace connectivity**
  - Background: Tangled traces within a single requirements set
  - Trace analysis spreadsheet (MS Excel)
  - Network flowdown diagram (MS Project)
- **Examples of end-to-end views**
  - Revisiting the tangled traces
  - Looking across 5 specifications
  - Beginning a new project
  - Supplementing Risk Assessments

**We strive to find issues as early in the life-cycle as possible**

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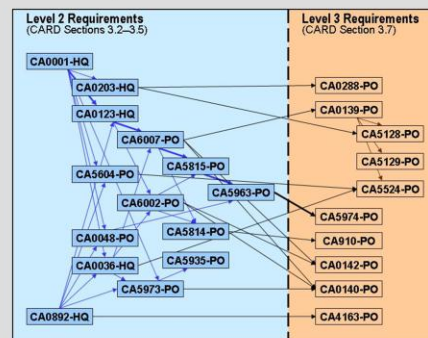
### Acronyms

<b>CARD</b>	Constellation Architecture Requirements Document
<b>FSW</b>	Flight Software
<b>GPM</b>	Global Precipitation Measurement
<b>ICESat-2</b>	Ice, Cloud, and land Elevation Satellite 2
<b>ID</b>	Identifier
<b>IV&amp;V</b>	Independent Validation and Verification
<b>MS</b>	Microsoft
<b>NASA</b>	National Aeronautics and Space Administration
<b>PBRA</b>	Portfolio Based Risk Assessment
<b>RBA</b>	Risk Based Analysis
<b>TIM</b>	Technical Issue Memorandum
<b>WV</b>	West Virginia

## Visual tools for analyzing trace connectivity Background (Tangled Traces)



- **CARD's parent-child trace table contains internal Level 2 links that sometimes reach the fifth generation before tracing to Level 3 requirements in CARD Section 3.7:**
  - 85 L2 reqts link directly to both L2 and L3 children
  - 10 L2 reqts are parents of other L2 reqts
  - 26 L2 reqts are both a child and parent of other L2 reqts
  - 60 L2 reqts are a child of other L2 reqts
  - 9 L2 reqts are 4<sup>th</sup> or 5<sup>th</sup> generation children of other L2 reqts
- **Internal Level 2 traces sometimes reach the fourth and fifth generation**
- **Direct links to L3 requirements exist for all five L2 generations**
- **Some Level 3 requirements have children, with some having direct links back to L2 requirements at a higher level than their L3 parent.**



**Tangled trace structure complicates assessment of proposed changes**  
(shown for 24 selected requirements)

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## Background

### Driving Event:

IV&V found tangled traces in the Constellation Architecture Requirements Document (CARD). This problem affected over 100 individual requirements.

A Technical Issues Memorandum (TIM) was submitted to the Project in October, 2007

A diagram highlighting this issue for 24 selected requirements was included in a briefing presented to the Project in February 2008 – and drew a far more motivated response than the detailed technical description submitted four months earlier.


### Lesson Learned:

While the value of diagrams like these was clear, developing them at the end of an analysis takes effort and time (usually at a time when deadlines begin to press).

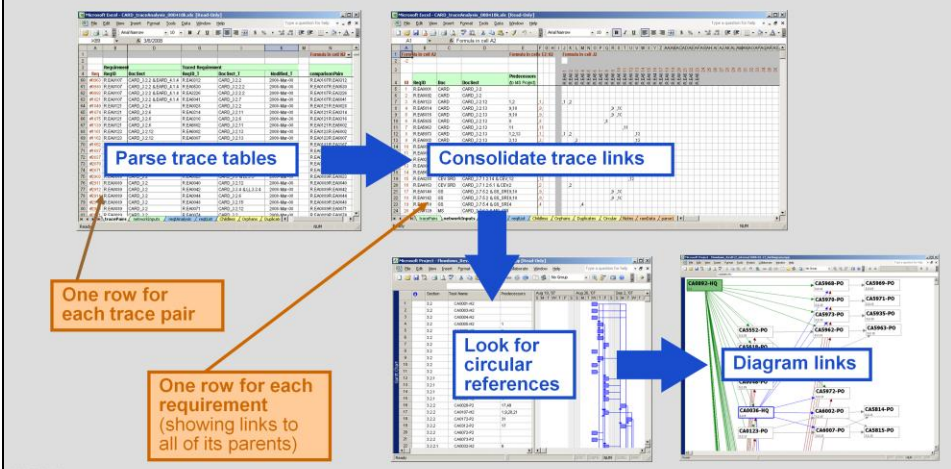
Any tools used for generating these diagram should also be used during the analysis itself (thereby saving time).

## Visual tools for analyzing trace connectivity

# Analyzing Trace Connectivity



- **MS Excel and MS Project used to analyze trace connectivity across a set of traces**
  - Looks for intra-level trace problems and circular references



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## Analyze Trace Connectivity

### Goal in Context:

A requirements-trace table contains parent-child links that can be used to produce a network diagram for analyzing trace complexity.

### Success Guarantee:

This activity produces a network diagram showing requirements flowdown, along with a listing of any trace errors encountered.

### Main Success Scenario:

- 1 Parse trace table
- 2 Consolidate trace links
- 3 Look for circular references
- 4 Diagram links

## Visual tools for analyzing trace connectivity Parsing Trace Tables



- MS Excel spreadsheet used to parse trace tables to produce a set of parent-child trace pairs

Microsoft Excel - CARD_TracAnalysis_080410.xls [Read-Only]										Type a question for help									
File Edit View Insert Format Tools Data Window Help										3/6/2008									
Arial Narrow										Formulas in cell R9 -									
K89																			
A B C D E F G H I J K L M N																			
Requirement										Traced Requirement									
ReqID DocSect										ReqID DocSect Modified comparisonPairs									
R.EA0107 CARD_3.2.2 & EARD_4.1.4										R.EA0312 CARD_3.2.2 2008-Mar-08 R.EA0107R.EA0312									
R.EA0530 CARD_3.2.2 & EARD_4.1.4										R.EA0530 CARD_3.2.2.2 2008-Mar-08 R.EA0107R.EA0530									
R.EA0107 CARD_3.2.2 & EARD_4.1.4										R.EA0226 CARD_3.2.2 2008-Mar-08 R.EA0107R.EA0226									
R.EA0107 CARD_3.2.2 & EARD_4.1.4										R.EA0041 CARD_3.2.7 2008-Mar-08 R.EA0107R.EA0041									
R.EA0107 CARD_3.2.6										R.EA0028 CARD_3.2.2 2008-Mar-08 R.EA0121R.EA0028									
R.EA0121 CARD_3.2.6										R.EA0014 CARD_3.2.11 2008-Mar-08 R.EA0121R.EA0014									
R.EA0121 CARD_3.2.6										R.EA0016 CARD_3.2.6 2008-Mar-30 R.EA0121R.EA0016									
R.EA0121 CARD_3.2.6										R.EA0002 CARD_3.2.11 2008-Mar-08 R.EA0121R.EA0002									
R.EA0123 CARD_3.2.12										R.EA0007 CARD_3.2.13 2008-Mar-08 R.EA0123R.EA0007									
R.EA0123 CARD_3.2.12										R.EA0007 CARD_3.2.13 2008-Mar-08 R.EA0123R.EA0007									
R.EA0111 CARD_3.2.6 & EARD_4.1.4										R.EA0167 CARD_3.3.6 & LL3.3.6 2008-Mar-08 R.EA0111R.EA0167									
R.EA0202 CARD_3.2 & EARD_4.1.2										R.EA0715 CARD_3.2.11 2008-Mar-08 R.EA0202R.EA0715									
R.EA0296 CARD_3.2.10										R.EA0476 CARD_3.2.10 2008-Mar-08 R.EA0296R.EA0476									
R.EA0296 CARD_3.2.10										R.EA0043 CARD_3.2.10 2008-Mar-08 R.EA0296R.EA0043									
R.EA0296 CARD_3.2.10										R.EA0051 CARD_3.2.10 2008-Mar-08 R.EA0296R.EA0051									
R.EA0839 CARD_3.2										R.EA0023 CARD_3.5 & LL3.5 2008-Mar-08 R.EA0839R.EA0023									
R.EA0839 CARD_3.2										R.EA0040 CARD_3.2.12 2008-Mar-08 R.EA0839R.EA0040									
R.EA0839 CARD_3.2										R.EA0042 CARD_3.3.4 & LL3.3.4 2008-Mar-08 R.EA0839R.EA0042									
R.EA0839 CARD_3.2										R.EA0044 CARD_3.2.6 2008-Mar-08 R.EA0839R.EA0044									
R.EA0839 CARD_3.2										R.EA0043 CARD_3.2.15 2008-Mar-08 R.EA0839R.EA0043									
R.EA0839 CARD_3.2										R.EA0071 CARD_3.2.12 2008-Mar-08 R.EA0839R.EA0071									
R.EA0074 CARD_3.2										R.EA0074 CARD_3.2 2008-Mar-08 R.EA0074R.EA0074									

This tab uses a "clean" set of traces (no duplicates, orphans or childless) to generate comparison pairs

One row for each trace pair

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## Parse Trace Table

### Goal in Context:

IV&V receives requirements-trace information from many sources (including documents and on-line tools), from which the needed parent-child trace pairs must be extracted for further analysis. These sources present the information in a wide variety of formats and may contain errors (such as duplicate entries, childless parents and orphans).

### Success Guarantee:

This activity will produce a "clean" list of parent-child pairs (in an Excel spreadsheet with one row per pair), along with a listing of any trace errors encountered.

### Main Success Scenario:

- Paste copy of trace source into an Excel spreadsheet
- Copy parent and child identifiers (and any related info) to separate tab
- Remove blank rows (if any)
- Replicate info that had been removed to improve readability (as needed)
- Search for duplicates
- Remove orphan and childless traces
- Generate "clean" list of parent-child pairs in separate tab
- Assemble a working list of requirement IDs
- Generate lists of orphans and childless requirements in separate tabs

### Notes tab lists detailed steps

Step	Description
1	Paste copy of trace source into an Excel spreadsheet
2	Copy parent and child identifiers (and any related info) to separate tab
3	Remove blank rows (if any)
4	Replicate info that had been removed to improve readability (as needed)
5	Search for duplicates
6	Remove orphan and childless traces
7	Generate "clean" list of parent-child pairs in separate tab
8	Assemble a working list of requirement IDs
9	Generate lists of orphans and childless requirements in separate tabs



## Visual tools for analyzing trace connectivity Consolidating Trace Links



- MS Excel spreadsheet used to correlate trace links and produce "Predecessors" for MS Project

Columns for up to 16,383 parents

Cells for each intersection (Example: 500 reqts needs ~100,000 cells and takes 9 minutes to calculate)

One row for each requirement (showing links to all of its parents)

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## Consolidate Trace Links

### Goal in Context:

Preparing the parent-child trace information (one row per pair) for producing a network diagram first requires finding all of the direct parents (but not grandparents) associated with each requirement. This activity follows the Parse Trace Tables steps.

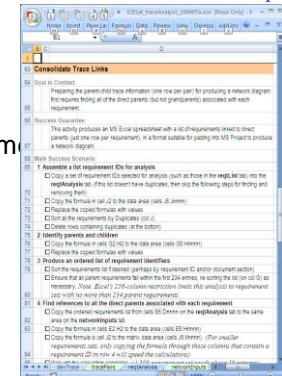
### Success Guarantee:

This activity produces an MS Excel spreadsheet with a list of requirements linked to direct parents (just one row per requirement), in a format suitable for pasting into MS Project to produce a network diagram.

### Main Success Scenario:

- Assemble list of all parent requirement identifiers
- Identify parents and children
- Produce an ordered list of requirement identifiers
- Find references to all the direct parents associated with each requirement

### Notes tab lists detailed steps

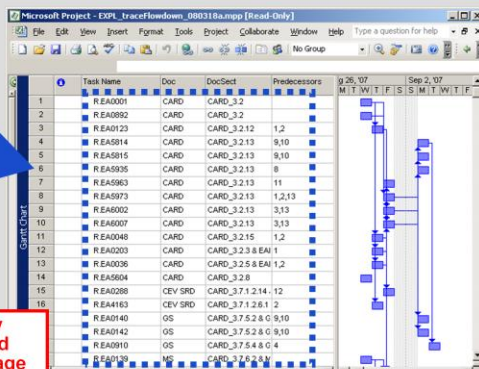


## Visual tools for analyzing trace connectivity Looking for Circular References



- Pasting “Predecessors” into MS Project’s Gantt view identifies any circular references

ReqID	Doc	DocSect	Predecessors
1	REAO001	CARD	CARD_3.2
2	REAO002	CARD	CARD_3.2
3	REAO003	CARD	CARD_3.2.12
4	REAO004	CARD	CARD_3.2.13
5	REAO005	CARD	CARD_3.2.13
6	REAO006	CARD	CARD_3.2.13
7	REAO007	CARD	CARD_3.2.13
8	REAO008	CARD	CARD_3.2.13
9	REAO009	CARD	CARD_3.2.13
10	REAO010	CARD	CARD_3.2.13
11	REAO011	CARD	CARD_3.2.13
12	REAO012	CARD	CARD_3.2.13
13	REAO013	CARD	CARD_3.2.13
14	REAO014	CARD	CARD_3.2.13
15	REAO015	CARD	CARD_3.2.13
16	REAO016	CARD	CARD_3.2.13
17	REAO017	CARD	CARD_3.2.13
18	REAO018	CARD	CARD_3.2.13
19	REAO019	CARD	CARD_3.2.13
20	REAO020	CARD	CARD_3.2.13
21	REAO021	CARD	CARD_3.2.13
22	REAO022	CARD	CARD_3.2.13
23	REAO023	CARD	CARD_3.2.13
24	REAO024	CARD	CARD_3.2.13
25	REAO025	CARD	CARD_3.2.13
26	REAO026	CARD	CARD_3.2.13
27	REAO027	CARD	CARD_3.2.13
28	REAO028	CARD	CARD_3.2.13
29	REAO029	CARD	CARD_3.2.13
30	REAO030	CARD	CARD_3.2.13
31	REAO031	CARD	CARD_3.2.13
32	REAO032	CARD	CARD_3.2.13
33	REAO033	CARD	CARD_3.2.13
34	REAO034	CARD	CARD_3.2.13
35	REAO035	CARD	CARD_3.2.13
36	REAO036	CARD	CARD_3.2.13
37	REAO037	CARD	CARD_3.2.13
38	REAO038	CARD	CARD_3.2.13
39	REAO039	CARD	CARD_3.2.13
40	REAO040	CARD	CARD_3.2.13
41	REAO041	CARD	CARD_3.2.13
42	REAO042	CARD	CARD_3.2.13
43	REAO043	CARD	CARD_3.2.13
44	REAO044	CARD	CARD_3.2.13
45	REAO045	CARD	CARD_3.2.13
46	REAO046	CARD	CARD_3.2.13
47	REAO047	CARD	CARD_3.2.13
48	REAO048	CARD	CARD_3.2.13
49	REAO049	CARD	CARD_3.2.13
50	REAO050	CARD	CARD_3.2.13
51	REAO051	CARD	CARD_3.2.13
52	REAO052	CARD	CARD_3.2.13
53	REAO053	CARD	CARD_3.2.13
54	REAO054	CARD	CARD_3.2.13
55	REAO055	CARD	CARD_3.2.13
56	REAO056	CARD	CARD_3.2.13
57	REAO057	CARD	CARD_3.2.13
58	REAO058	CARD	CARD_3.2.13
59	REAO059	CARD	CARD_3.2.13
60	REAO060	CARD	CARD_3.2.13
61	REAO061	CARD	CARD_3.2.13
62	REAO062	CARD	CARD_3.2.13
63	REAO063	CARD	CARD_3.2.13
64	REAO064	CARD	CARD_3.2.13
65	REAO065	CARD	CARD_3.2.13
66	REAO066	CARD	CARD_3.2.13
67	REAO067	CARD	CARD_3.2.13
68	REAO068	CARD	CARD_3.2.13
69	REAO069	CARD	CARD_3.2.13
70	REAO070	CARD	CARD_3.2.13
71	REAO071	CARD	CARD_3.2.13
72	REAO072	CARD	CARD_3.2.13
73	REAO073	CARD	CARD_3.2.13
74	REAO074	CARD	CARD_3.2.13
75	REAO075	CARD	CARD_3.2.13
76	REAO076	CARD	CARD_3.2.13
77	REAO077	CARD	CARD_3.2.13
78	REAO078	CARD	CARD_3.2.13
79	REAO079	CARD	CARD_3.2.13
80	REAO080	CARD	CARD_3.2.13
81	REAO081	CARD	CARD_3.2.13
82	REAO082	CARD	CARD_3.2.13
83	REAO083	CARD	CARD_3.2.13
84	REAO084	CARD	CARD_3.2.13
85	REAO085	CARD	CARD_3.2.13
86	REAO086	CARD	CARD_3.2.13
87	REAO087	CARD	CARD_3.2.13
88	REAO088	CARD	CARD_3.2.13
89	REAO089	CARD	CARD_3.2.13
90	REAO090	CARD	CARD_3.2.13
91	REAO091	CARD	CARD_3.2.13
92	REAO092	CARD	CARD_3.2.13
93	REAO093	CARD	CARD_3.2.13
94	REAO094	CARD	CARD_3.2.13
95	REAO095	CARD	CARD_3.2.13
96	REAO096	CARD	CARD_3.2.13
97	REAO097	CARD	CARD_3.2.13
98	REAO098	CARD	CARD_3.2.13
99	REAO099	CARD	CARD_3.2.13
100	REAO100	CARD	CARD_3.2.13



MS Project rejects any circular references and generates error message

## Look for Circular References

### Goal in Context:

Requirements-trace information may contain circular-reference errors. These errors, which may be direct (A to B and B to A) or indirect (such as A to B, B to C and C to A), must be identified before proceeding to diagram the trace. This activity follows the Consolidate Trace Links steps.

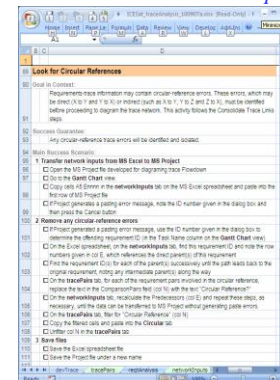
### Success Guarantee:

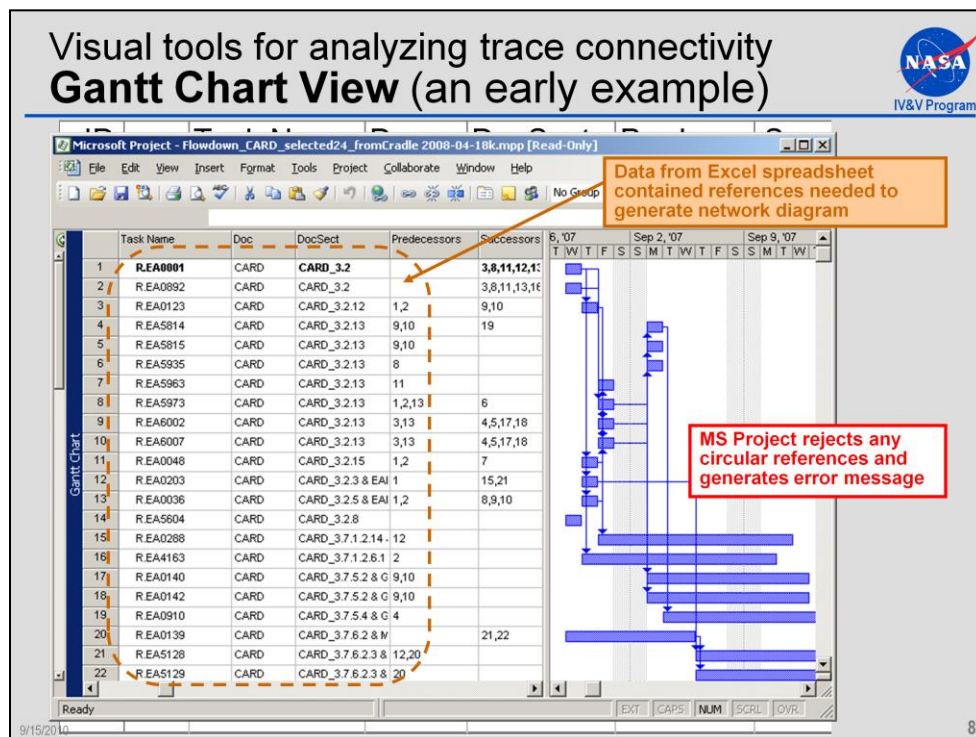
Any circular-reference errors in the trace will be identified and isolated.

### Main Success Scenario:

- 1 Transfer network inputs from MS Excel into MS Project
- 2 Remove any circular-reference errors
- 3 Save the Project file

### Notes tab lists detailed steps

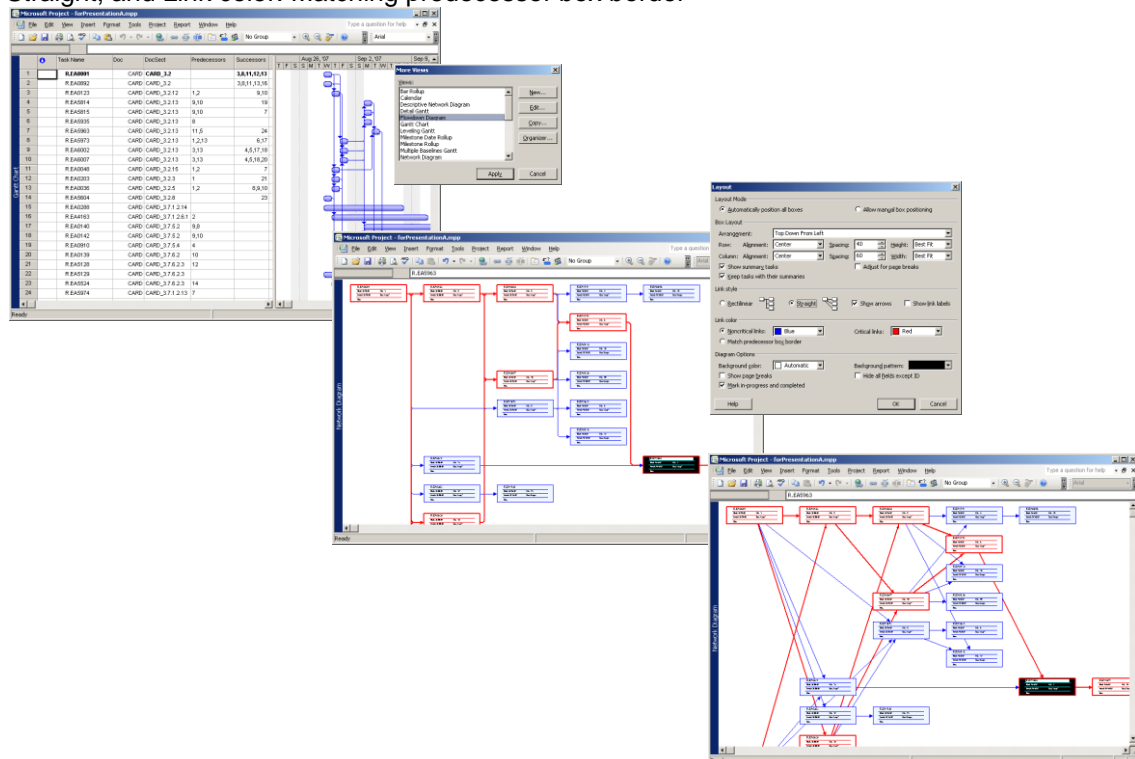




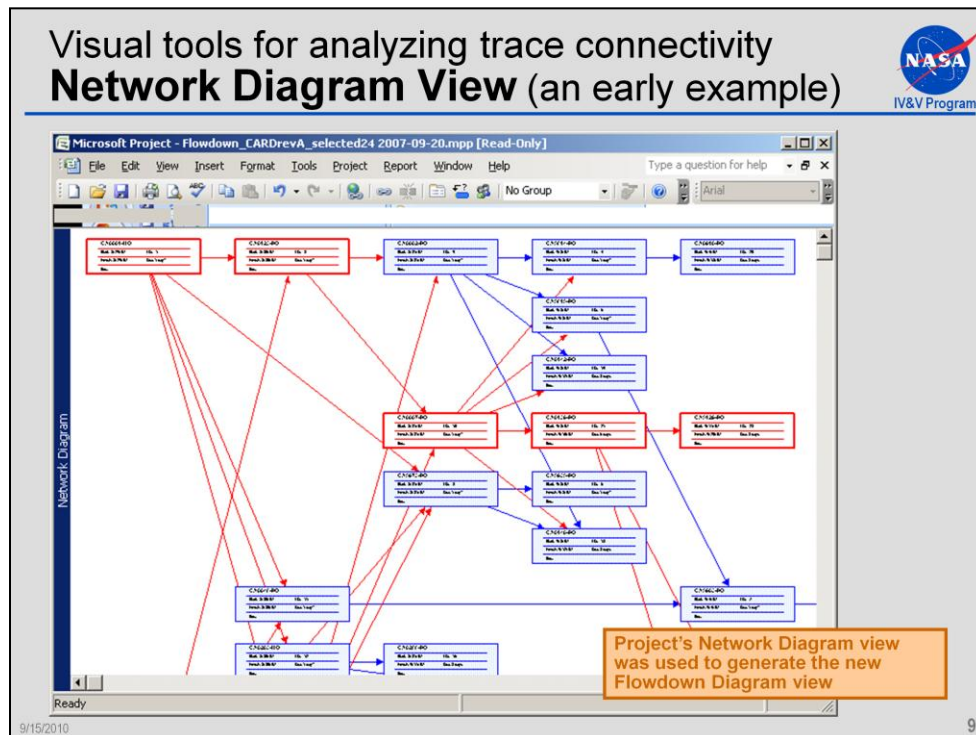
## Walk-Through on how a new MS Project view was customized for requirements traces (Part 1 of 2)

Use More Views dialog to copy Network Diagram view to a view named Flowdown Diagram

Use Layout dialog box to select Layout Mode: Allow manual box positioning; Link style: Straight; and Link color: Matching predecessor box border



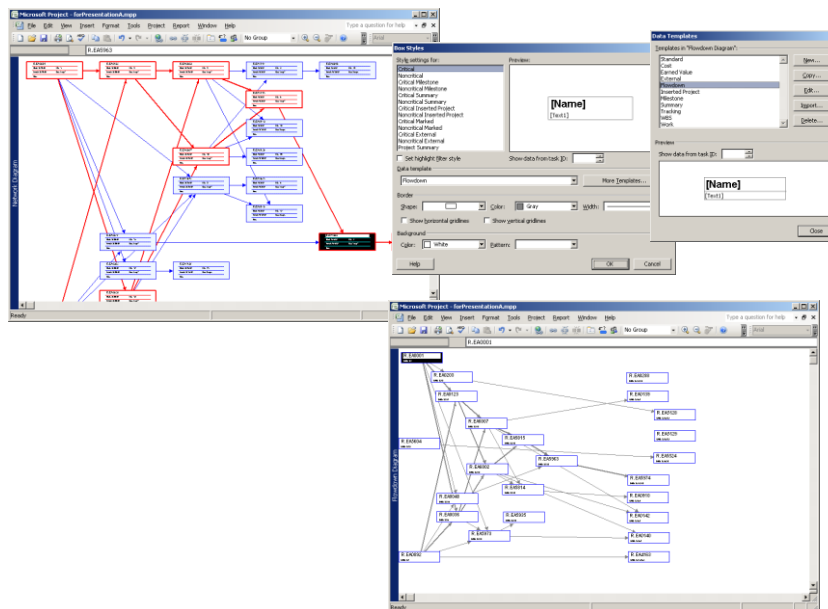





## Walk-Through on how a new MS Project view was customized for requirements traces (Part 2 of 2)

Use Box Styles dialog box to format a new data template that highlights Requirement IDs

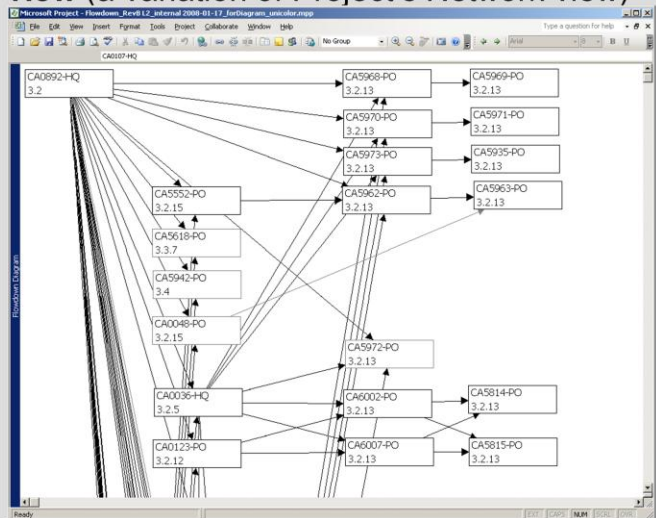
Save new template



## Visual tools for analyzing trace connectivity Diagramming Trace Links



- MS Project shows dependencies in the Flowdown view (a variation of Project's Network view)**



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## Diagram Trace Links

### Goal in Context:

The parent-child links that can be used for a selected set of requirements to produce a network diagram for analyzing trace complexity. This activity follows the Look for Circular References steps.

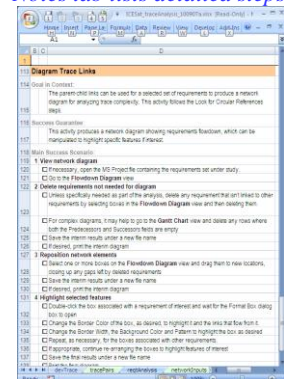
### Success Guarantee:

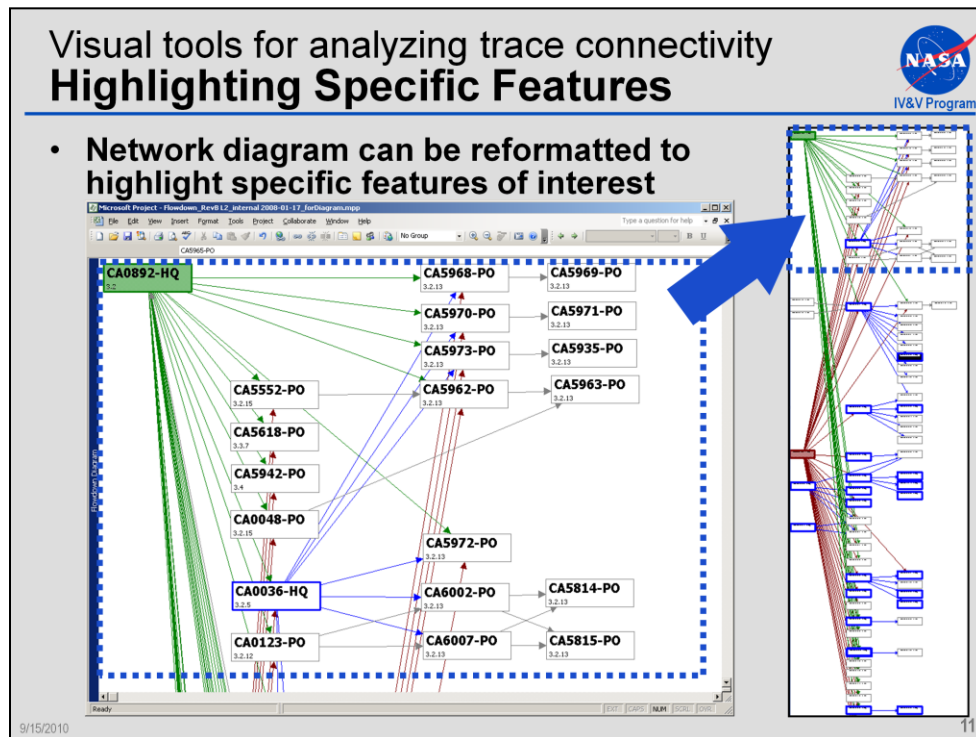
This activity produces a network diagram showing requirements flowdown, which can be manipulated to highlight specific features if interest.

### Main Success Scenario:

- 1 View Flowdown Diagram
- 2 Delete requirements not needed for diagram
- 3 Reposition network elements
- 4 Highlight selected features *(by coloring the boxes for selected parents)*

*Notes tab lists detailed steps*

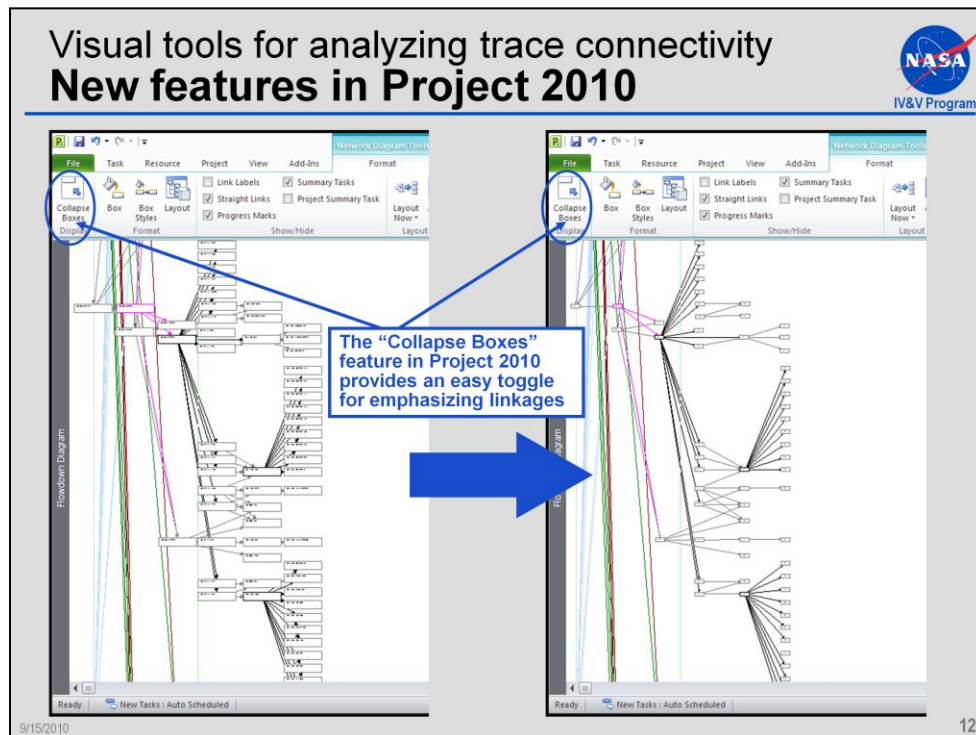




**Begin by taking delight in externals**

*In every new situation  
 we must start all over again  
 like children,  
 cultivate a passionate interest  
 in things and events,  
 and begin by taking delight in externals,  
 until we have the good fortune  
 to grasp the substance.*

**– Johann Wolfgang von Goethe**  
 Wilhelm Meisters Wanderjahre (I, 3, 1829)



## New features in Office 2010 extend the applicability of the visual analysis techniques originally developed with Office 2003

### Excel:

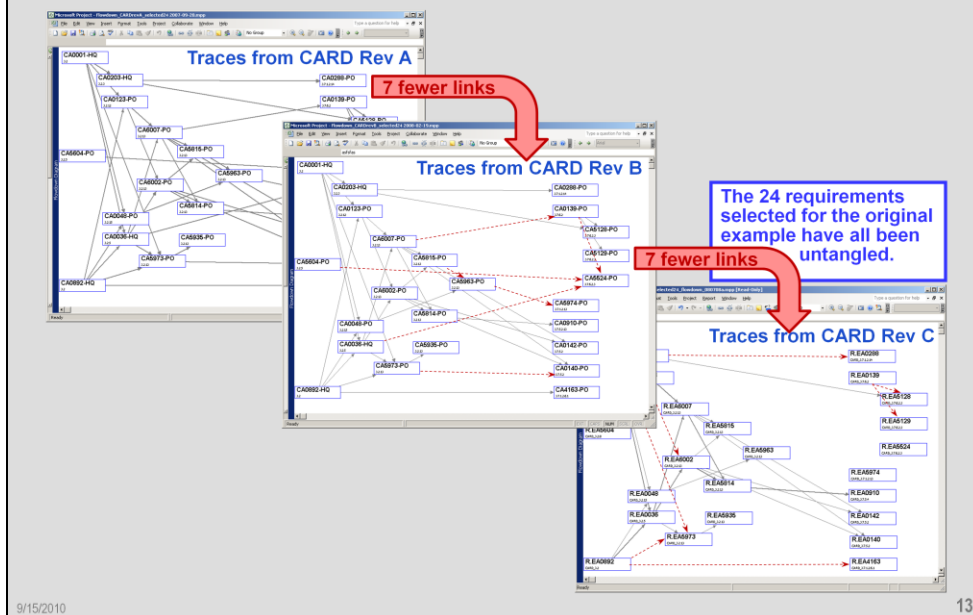
Excel 2007 and later now allow 16,384 columns. Since one column is needed for each parent in the Network Inputs tab, future analyses aren't bound by the original 256-column limit.

### Project:

Project 2010 offers a Collapse Boxes feature that makes it easy to toggle the view to emphasize the links – which gives the Flowdown View a more tree-like structure.

Project 2010 also offers an alignment feature that makes it easier to reposition boxes neatly enough for report graphics

## Example #1 Revisiting the tangled traces (CxSI)

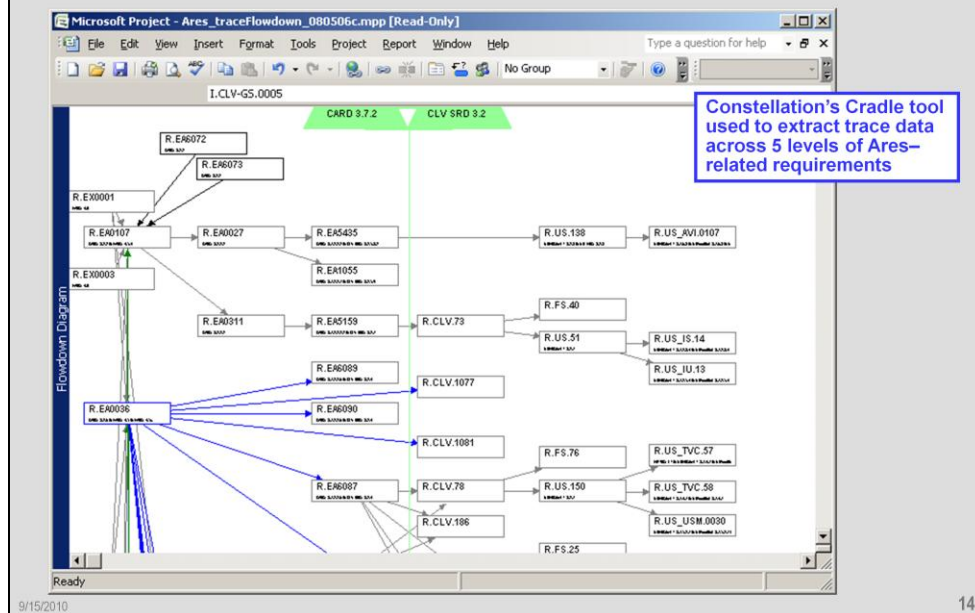


## Constellation Architecture Requirements Document (CARD)

This analysis followed the 24 requirements originally selected from the approximately 160 Level 2 requirements (which were traced to about 500 Level 3 requirements).



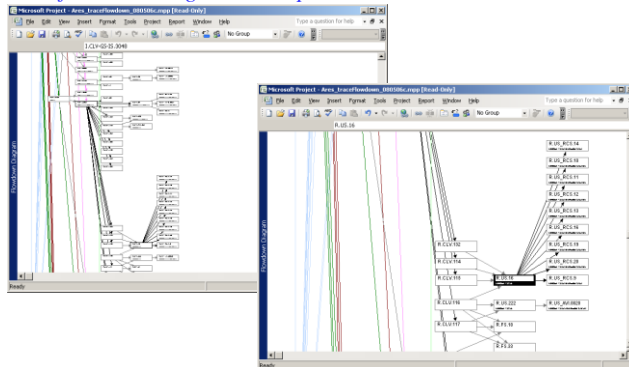
## Example #2 Looking across 5 specifications (Ares)



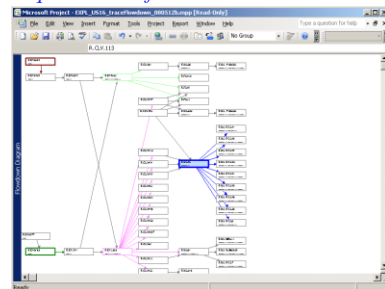
## CxAres

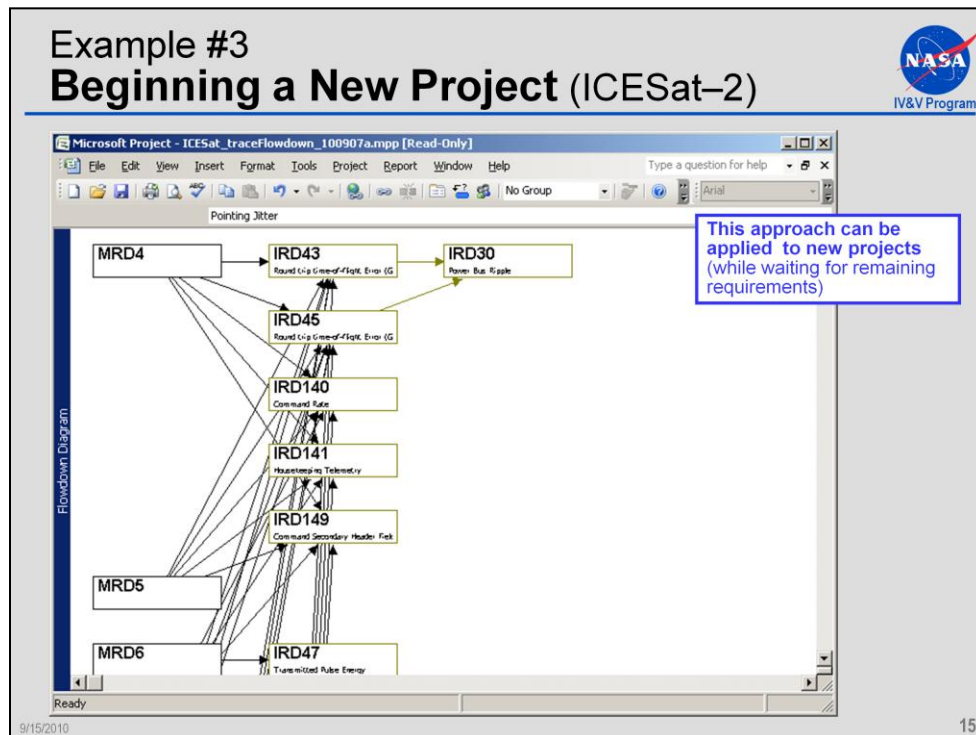
Approximately 450 related requirements (as of mid-2008)

*Scan for interesting / unusual patterns*



*Copy the file, then re-position (and delete) as needed to focus the analysis on a requirement of interest*

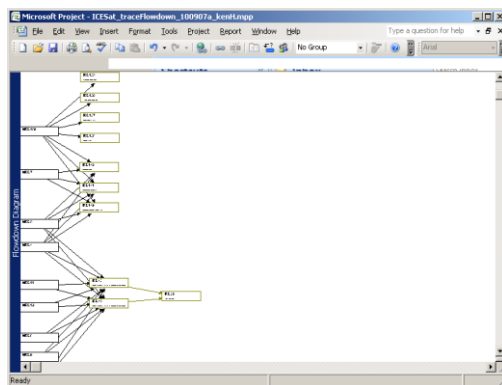




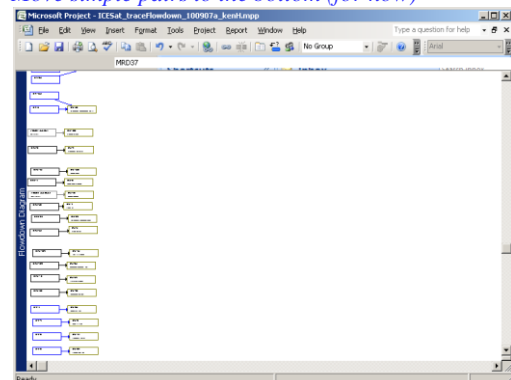
## ICESat-2

Approximately 130 instrument requirements (mid-2010), with traces to about 40 mission requirements and about 100 interface requirements.

*Group tangled requirements together*



*Move simple pairs to the bottom (for now)*



## Example #4 Supplementing Risk Assessments (GPM)



GPM RBA 201008021\_KenH.xlsx - Microsoft Excel

	B	D	E	F	G	H	N	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM
1																					
2																					
3																					
4	System Goals				PBRA	CFE	CFS	GNC	Apps	CDH	Apps	EDA	TO	CI	SD	CL	CG				
5	Measure Global Precipitation																				
6	Launch and Achieve Initial Orbit				5 x 2.8																
7	Fly Core Spacecraft in Circular Orbit							X	X	X	X	X	X								
8	Checkout Spacecraft				4 x 2.2																
9	Achieve Sun Point Mode				3H-IM			X	X	X	X	X	X								
10	Solar Array Deployed				2H-I			X	X	X	X	X	X								
11	Circularize Orbit				1L			X	X	X	X	X	X								
12	Instrument Power On, Test,				2H-5M-1L																
13	Spacecraft Subsystem Test /				2M			X	X	X	X	X	X								
14	Complete Early Orbit Commanded				3H-I			X	X	X	X	X	X								
15	Fly in Required Orbit				4 x 2.2																
16	Maintain Proper Orbit - Core				None			X	X	X	X	X	X								
17	Obtain Science Data				3 x 2.2																
18	Calibrate Precipitation Instruments				1H			X	X			X	X								
19	Gather Science Data from Instrument				1L			X	X			X	X								
20	Download Science Data				1M-1L														X		
21	Maintain Health and Safety of Spac				4.5																
22	Maintain Propulsion System				5H-4M-1L			X													
23	Maintain Flight Computer Resources				ot include			X	X	X	L345										
24	Maintain SIC Power Positive State				2H-4M-1L						X	L345							X		
25	Uplink SIC Commands				ot include						X							X	L345	L345	
26	Download HK Data				ot include			X	X	L345		L345						X	L345	L345	L345
27	Maintain Thermal Safe SIC				4H-1L			X	X												
28	Analyze and Respond to Faults				1H-5M-1L			X	X	X	L345	L345	X		L345	X		X	L345	L345	L345
29	Process Science Data				2 x 1.6																
30	Collect & Store SIC Telemetry				ot include																
31	Construct/Validate SIC Command Slot				ot include																
32	Construct/Validate SIC Command Slot				ot include																
33	Construct/Validate SIC Command Slot				ot include																
34	RBA	xRef	oldPBRA	corrL3	L3L4	L4L5															

As requirements for software components are identified, they can be associated with higher-level requirements (and with system behaviors identified by IV&V)

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## Visual Analysis of Requirements Flowdown **Summary**



- **Components within MS Office can support visual analysis and reporting**
- **Visual techniques can aid**
  - Reporting IV&V findings
  - Supporting IV&V analyses